



Cairo University

Effect of Flexural and Shear Reinforcement on the Punching Behavior of Reinforced Concrete Flat slabs

By

Amr Bakr Ismail

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
Structural Engineering

FACULTY OF ENGINEERING CAIRO UNIVERSITY
GIZA, EGYPT
2018

**Effect of Flexural and Shear Reinforcement on the Punching Behavior of
Reinforced Concrete Flat slabs**

By

Amr Bakr Ismail

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
Structural Engineering

Under the Supervision of

Prof. Dr. Hany Abdalla

Professor of Structural Engineering Department
Faculty of Engineering, Cairo
University

Dr. Rasha T.S. Mabrouk

Associate Professor of Structural
Engineering Department
Faculty of Engineering, Cairo
University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

Effect of Flexural and Shear Reinforcement on the Punching Behavior of Reinforced Concrete Flat slabs

By
Amr Bakr Ismail

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
Structural Engineering

Approved by the
Examining Committee

Prof. Dr. Hany Ahmed Abdalla

(Thesis Main Advisor)

Professor of Concrete Structures, Cairo University

Prof. Dr. Akram M.A.Torkey

(Internal Examiner)

Professor of Concrete Structures , Cairo University

Prof. Dr. Ibrahim Galal Shaaban,

(External Examiner)

Professor of Concrete Structures , Shobra faculty, Benha University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

Engineer's Name: Amr Bakr Ismail
Date of Birth: 5/8/1990
Nationality: Egyptian
E-mail: Amr_bakr@rocketmail.com
Phone: 01285343464
Address: El TAHRIR street, Doki, Giza, Egypt
Registration Date: 01/10/2015
Awarding Date:/....../2018
Degree: Master of Science
Department: Structural Engineering



Supervisors:

Prof. Dr. Hany Abdalla
Dr. Rasha T.S. Mabrouk

Examiners:

Prof. Dr. Hany Ahmed Abdalla (Thesis Main Advisor)
Prof. Dr. Akram M.A. Torkey (Internal Examiner)
Prof. Dr. Ibrahim Galal Shaaban (External Examiner)
Professor of Concrete Structures , Shobra faculty, Benha University

Title of Thesis:

Effect of Flexural and Shear Reinforcement on the Punching Behavior
of Reinforced Concrete Flat slabs

Key Words:

Punching, flat slabs, flexural reinforcement, shear reinforcement, crack pattern.

Summary:

In this research, seven samples were tested in the laboratory, representing a half- scaled model . The samples were a flat slabs with dimensions of 1050 x 1050 mm and a thickness of 100 mm. They were loaded with a square column 150 x 150 mm. Some variables were considered, such as distance between stirrups , width of the stirrups , number of branches of the stirrups and number of longitudinal bars at the column-slab connection. The experimental results were compared to those estimated by the Egyptian and international codes . The results showed that the punching strength increased with the increase of flexural reinforcement ratio and increase of stirrups.

ACKNOWLEDGMENTS

So many people have contributed so much to this Thesis; it is difficult to know where to begin.

I would like to express my most sincere gratitude and appreciation to my advisor, Prof. Dr.Hany Abdalla for his guidance, encouragement, and patience throughout the completion of my thesis work. I would like also to thank him for many helpful suggestions for verification of many problems which are included in the thesis and helping me to understand some topics. Thanks for him for reading my thesis and offering me a great deal of important and relevant feedback. I can't forget his interest in this thesis and that he considered it important and useful study for engineers. My co. advisor, Dr. Rasha T.S. Mabrouk has provided me with invaluable help and practical suggestions. I especially thank her for her advice and guidance in the best scientific researches that help me in my research . I would also to thank her for her deep cooperation during my research.

Finally, I must thank my Mum and Dad, who provided so much help and support. And of course, I want to thank all of those whose help makes the difference in my life. To my family, for being the light, joy, and fuel of my existence and for being my constant inspiration and support. For all I dedicate Thesis. Happy reading!

Table of Contents

Acknowledgments	i
Table of Contents	ii
List of Tables	iv
List of Figures.....	v
Abstract.....	viii
CHAPTER (1): Introduction	1
1.1 Introduction	1
1.2 Objectives.....	3
1.3 Organization of thesis	4
CHAPTER (2): literature Review	5
2.1 General.....	5
2.2 Overview of Previous research	5
2.3 Methods of Punching shear analysis	7
2.3.1 Mechanical model	7
2.3.2 Brooms model	9
2.3.3 Truss model	11
2.3.4 Strip model	13
2.4 Codes Provisions.....	14
2.4.1 The egyptian code of practice 2003 - 2007	14
2.4.2 The american code ACI 318-08	14
2.4.2.1 Slabs without shear reinforcement.....	14
2.4.2.2 Slabs with shear reinforcement	15
2.4.3 The euro code (e c 2 - 2004).....	20
2.4.3.1 Slabs without shear reinforcement.....	20
2.4.3.2 Slabs with shear reinforcement	22
2.4.4 The candian standard code	23
2.4.5 The british standard code	25
2.4.6 The german national annex	28
2.5 Parameters Governing Shear Strength of Flat Slabs	29
2.5.1 Concrete strength	29
2.5.2 Ratio and arrangement of reinforcing steel	30
2.5.3 Aspect ratio of loaded area.....	30
2.5.4 Size effect	30
2.5.5 Concrete cover.....	30
2.5.6 Perimeter to depth	30
2.6 Shear Reinforcement types	31

2.6.1	Shear reinforcement types	31
2.6.1.1	Closed stirrups	31
2.6.1.2	Bent – up bars	31
2.6.1.3	Structural steel shear heads	32
2.6.1.4	Shear studs.....	32
2.7	Failure Mechanisms	33
CHAPTER 3 : Experimental Program		36
3.1	Introduction.....	36
3.2	Experimental Program	36
3.3	Materials	39
3.4	Casting Concrete.....	42
3.5	Test Setup.....	44
3.6	Instrumenation	45
3.7	Loading Procedures	46
CHAPTER(4) : Experimental Results		47
4.1	Crack pattern.....	47
4.2	Experimental Results	53
CHAPTER(5) : Analysis and Discussion		62
5.1.	Effect of Spacing between Stirrups for Group A.....	62
5.2.	Effect of Spacing between Stirrups for Group B.....	64
5.3.	Effect of Spacing between Stirrups for Group C.....	66
5.4.	Effect of Spacing between Stirrups for Group D.....	68
5.5	Comparison of the Experimental Results with Codes.....	70
CHAPTER (6) : Conclusion		75
6.1	Introduction.....	75
6.2	Conclusion	75
6.3	Future Research	75
References.....		77

List of Tables

Table (2.1)1 Reinforcement details of the experimental previous program	7
Table (3.1) Details of the tested samples	37
Table (3.2) Design of the concrete mix	39
Table (3.3) Concrete standard cubes test results	40
Table (4.1). Experimental results of the tested slabs	52
Table (5.1). Experimental results for Group A.....	62
Table (5.2). Experimental results for Group B.....	64
Table (5.3). Experimental results for Group C.....	66
Table (5.4). Experimental results for Group D.....	68
Table (5.5) Comparison of experimental results with design codes	72
Table (5.6) Comparison of experimental results with the new equation for egyptian code	73
Table (5.7) Comparison of experimental results with the new equation for egyptian code on the previous experimental results for literature review (Hegab2017)	73

List of Figures

Figure 1.1 Building collapsed due to punching failure	2
Figure 1.2 The main concept of the punching failure	3
Figure 1.3 Various punching failure zones	3
Figure 2.1 Selected models of Kinunen and nyldander	6
Figure 2.2 Mechanical model by Kinunen and nyldander	9
Figure 2.3 High Radial compression stresses at failure by Brooms	11
Figure 2.4 Truss model by Alexnder and simmonds	12
Figure 2.5 Layout of Radial strips into strip model	13
Figure 2.6 Punching shear perimeter	15
Figure 2.7 Shear stress distribution alpng sec. for interior and edge column	17
Figure 2.8 Single or muliple leg stirrups	19
Figure 2.9 Arrangement of stirrups for interior column	19
Figure 2.10 Arrangement of stirrups for edge column	20
Figure 2.11 Control perimeter according to EC2- 2004	21
Figure 2.12 Control perimeter according to EC2- 2004 for other shapes	21
Figure2.13 Control perimeter according to EC2- 2004 for punching shear verification out side	22
Figure 2.14 Punching shear perimeter (BS).....	26
Figure 2.15 Typical Arrangement of shear studs and critical sections outside shear reinforced zone (BS8110) 28	28
Figure 2.16 Control perimeter According to NAD 2011	29
Figure 2.17 Closed stirrups	31
Figure 2.18 Bent – up bars	32
Figure 2.19 Shear heads	32
Figure 2.20 Shear studs	33
Figure 2.21 Shear failure into flat plates	33
Figure 2.22 Transfer of forces between floor and edge column	34
Figure 2.23 Transfer of forces between floor and interior column	35
Figure 2.24 Transfer of forces between floor andcorner column	35
Figure 2.25 Punching shear failure under combined shear and unbalanced moments	35
Figure 3.1 Reinforcement details of control sample S0.....	37
Figure 3.2 Typical cross section for samples S1 to S6	37

Figure 3.3 Reinforcement details of tested samples	39
Figure 3.4 Crushing process of standard concrete cubes	41
Figure 3.5 Standard cubes after Crushing process	41
Figure 3.6 Formwork setup and steel installation	42
Figure 3.7 After pouring of the concrete mix in the formwork	43
Figure. 3.8 Loading setup	44
Figure. 3.9 Layout and alignment of the testing frame	44
Figure3.10 schematic view of the test setup	45
Figure3.11 Locations of the strain gauges of flexure steel	45
Figure3.12 Locations of the strain gauges of stirrups.....	46
Figure 4.1a. Crack patter of tested slab S0	46
Figure 4.1b Crack pattern for sample S1	46
Figure 4.1c Crack pattern of S2	47
Figure 4.1d Crack pattern of S3	47
Figure 4.1e Crack pattern of S4	48
Figure 4.1f Crack pattern of S5.....	48
Figure 4.2a Crack pattern of S6	49
Figure 4.2b Failure of specimen S6 (elevation)	50
Figure 4.3 Load deflection of S0	51
Figure 4.4Load deflection of S1	52
Figure 4.5Load deflection of S2	53
Figure 4.6 Load deflection of S3	54
Figure 4.7 Load deflection of S4	55
Figure 4.8 Load deflection of S5	55
Figure 4.9 Load deflection of S6	56
Figure (4.10): Load strain curve for flexural tension steel S1	56
Figure (4.11): Load strain curve for stirrup at d/2 from column face S1.....	57
Figure (4.12): Load strain curve for flexural tension steel S2.....	57
Figure (4.13): Load strain curve for stirrup at d/2 from column face S2.....	58
Figure (4.14): Load strain curve for flexural tension steel S3.....	58
Figure (4.15): Load strain curve for stirrup at d/2 from column face S3.....	59
Figure (4.16): Load strain curve for flexural tension steel S4.....	59
Figure (4.17): Load strain curve for stirrup at d/2 from column face S4.....	60
Figure (4.18): Load strain curve for flexural tension steel S5.....	60

Figure (4.19): Load strain curve for flexural tension steel S4.....	61
Figure 5.1 Effect of stirrups spacing on punching behavior.....	63
Figure 5.2 Load strain curve for stirrups for S1&S2	63
Figure 5.3 load strain curve for flexural tension steel for S1&S2	63
Figure 5.4 Effect of horizontal flexural reinforcement on punching behavior	64
Figure 5.5 Load strain curve for stirrups for S3&S4	64
Figure 5.6 Load strain curve for flexural tension steel for S1&S3&S4	65
Figure 5.7 Effect of stirrups width on punching behavior S5&S1	66
Figure 5.8 Load strain curve for stirrups for S1&S5	67
Figure 4.9 Effect of number of stirrups branches on punching behavior	68
Figure 5.10 Load strain curve for flexural tension steel for S1&S6	69
Figure 5.11 Cracking and ultimate punching capacity of the tested slabs	70

ABSTRACT

Punching is one of the most important phenomena to be considered during the design of reinforced concrete flat slabs. Three main factors affect the punching behavior; namely concrete compressive strength, horizontal flexural reinforcement, and vertical shear reinforcement in the form of stirrups, studs or other forms. This thesis is part of an ongoing research program conducted at the concrete laboratory of the Faculty of Engineering, Cairo University to assess the contribution of horizontal flexural reinforcement and vertical shear reinforcement on the punching behavior of reinforced concrete flat slabs. In the current research, seven half scale specimens are cast and tested. The specimens had dimensions of 1050x1050 mm and a total thickness of 100 mm. All specimens were connected to a square column of dimensions 150x150 mm and supported at the four corners with a span 950 mm. The parameters considered in this research included spacing between vertical stirrups, width of the stirrups, number of stirrups branches and the ratio of the horizontal flexural reinforcement. During testing, ultimate capacity, steel strain, cracking pattern and deformation were recorded. The experimental results were analyzed and compared to values estimated according to the Egyptian and international design codes.

The results of this research revealed the efficiency of flexural and shear reinforcement in resisting punching stresses. The punching strength increased with the increase of area of flexural reinforcement and the increase in number of stirrups in the vicinity of the slab- column connection.

CHAPTER (1): Introduction

1.1 Introduction

Flat slab is commonly used in multi-storey structures, office buildings and parking structures. It is called slab-column structure, which has architectural view and economical use of housing space. Despite the benefits of the flat slab system, one of the major design problems lies in Large bending moments and shear forces at slab-column connections. In addition punching shear failure occurs in a brittle way without warning signs. When punching shear failure occurs column and slab separate from each other which can lead to collapse the structure. In order to avoid the failure of slab-column connections around the column reinforcement profiles are provided such as bent bars, transverse hidden beams with stirrups, fibers, HSC and steel I-beams. These precautions improve the punching shear capacity and hence the strength of slabs.

Punching failure is a brittle failure caused by shear diagonal cracks developed through the full slab thickness forming a frustum pyramid in rectangular columns and a trenched cone in circular ones. Punching is a common failure that can be seen in reinforced concrete flat slabs as well as other structural elements such as foundations. Many factors affect the punching capacity of slabs such as concrete strength, column to slab aspect ratio, flexural reinforcement, shear reinforcement and boundary conditions. Design codes deal with the punching failure problem in different ways. For example, the current Egyptian Code of practice E.C.P. (203-2007) [1] highly underestimates the punching capacity by neglecting the contribution of the vertical and horizontal reinforcement in calculations. While, the American code (ACI318-14) [2] neglects the effect of the horizontal reinforcement and the European code Euro-Code 2 [3] considers both of them. In addition, the location of the critical section of punching varies among the design codes from half to double the effective slab depth measured from the column face.

Several analytical models were proposed over the past decade to simulate the punching behavior of concrete slabs. The first of these was the Kinnunen and Nylander model [4] who neglected the contribution of reinforcement to the punching capacity of concrete. Similar models were introduced. In addition there are other models such as the plasticity approach, shear friction model, truss model and yield line model. Such models give an indication of the complexity of the punching problem in concrete slabs.

Increasing the punching capacity of RC slabs can be done using different methods such as drop panels, shear reinforcement in the form of studs or stirrups and bent up bars. Strengthening of existing slabs in punching can be performed using advanced composite materials such as carbon fiber reinforced polymers (CFRP), and glass fiber reinforced polymer (GFRP). Ebead tested slab column connections strengthened with CFRP strips and GFRP laminates. Based on the test results, he concluded that the use of CFRP strips and GFRP laminates with the suggested dimensions were sufficient to achieve positive results for the flexural strengthened specimens. In addition, flexural strengthened specimens using CFRP strips showed an average gain in load capacity of 40 % over that of the un-strengthened specimens. Moreover, flexural strengthened specimens using GFRP laminates showed an average increase in load carrying capacity of 31 % compared to that of un-strengthened specimens.

Megally conducted a series of tests on slab column connections subjected to concentric and earthquake loads. He concluded that providing a slab column connection with drop panel increased the strength to the target value without significant improvement in ductility and energy absorption capacity. Megally and Ghali [5,6] conducted a series of reversed cyclic tests of edge slab column

connections reinforced with stud shear reinforcement. The test variables were the provision of stud shear reinforcement, the spacing between shear studs, and the value of shearing force transferred between the column and the slab. They concluded that, without shear reinforcement, slab column connections subjected to earthquakes may fail in a brittle punching shear mode at relatively low drift ratios. In addition, provision of shear studs significantly enhances the ductility and maximum inter-story drift ratios that the connections can undergo without punching failure.

Brooms proposed a combination of bent bars and stirrups to be installed in the column vicinity in order to eliminate the brittle punching shear failure of slab column connections. In his research, the tested specimens were provided with bent bars as hangers into the column in combination with stirrup cages from welded wire fabric over a fairly large area around the column. This concept turned out to be very effective in creating an extremely ductile structural system.

Out of the above mentioned strengthening systems, using flexural reinforcement in addition to stirrups proves to be the most practical method to be applied to enhance the punching behavior. This system is applied throughout the research program presented in this thesis. There are many parameters affect punching shear strength like reinforcement ratio, the compressive strength, size and geometry of column, type of reinforcement and the effective depth of the slab. Figure (1.1) shows an example to floor failure due to punching, while figures (1.2) and (1.3) illustrate the concept of the punching failure. The increase in reinforcement ratio while keeping increases the punching shear strength and prevents development of the tensile cracks due to bending which leads to a good transfer of loads in slab-column connection.

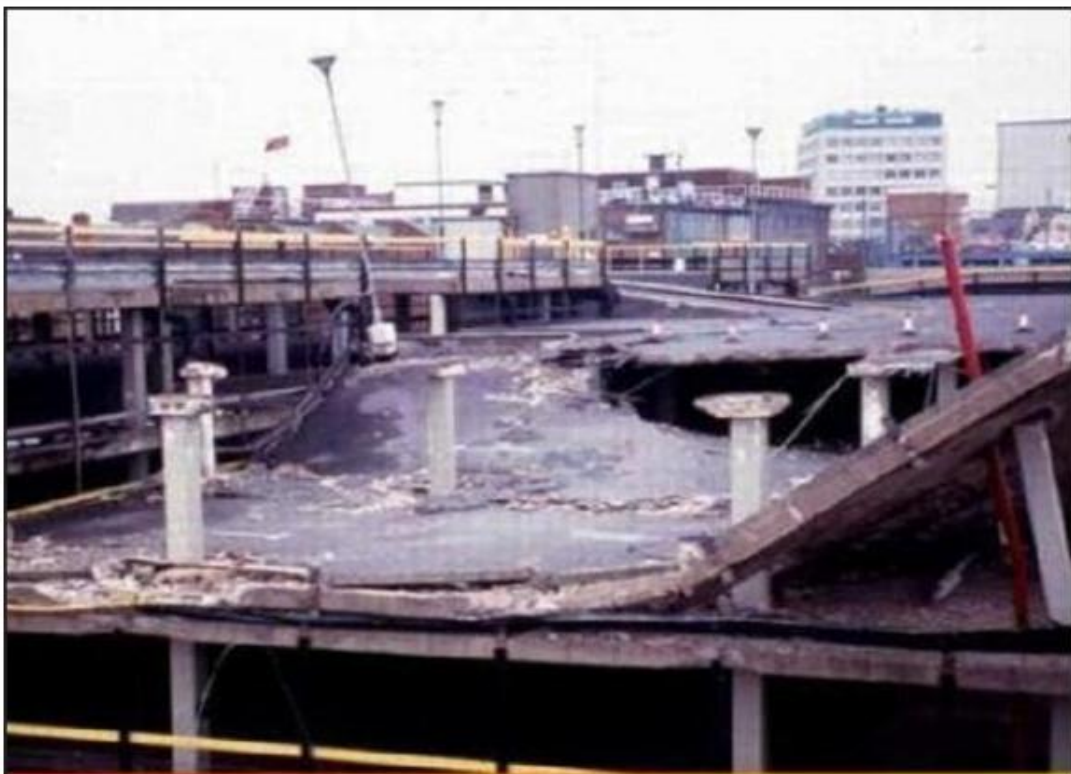


Figure (1.1): Building Collapsed due to punching failure

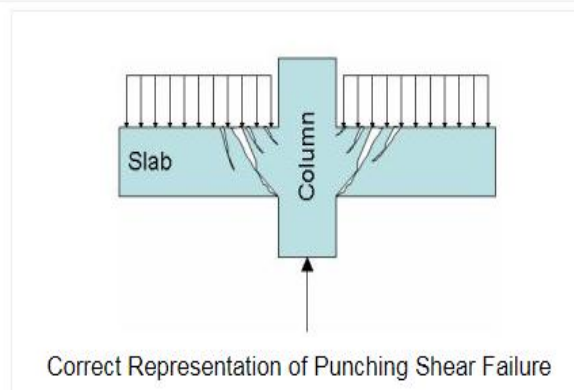
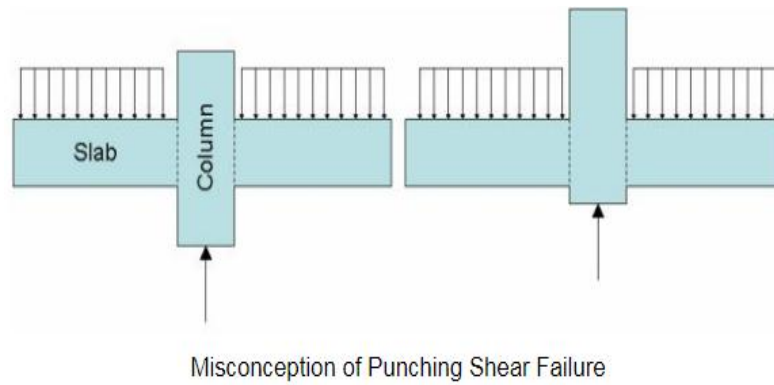


Figure (1.2): The main concept of the punching failure

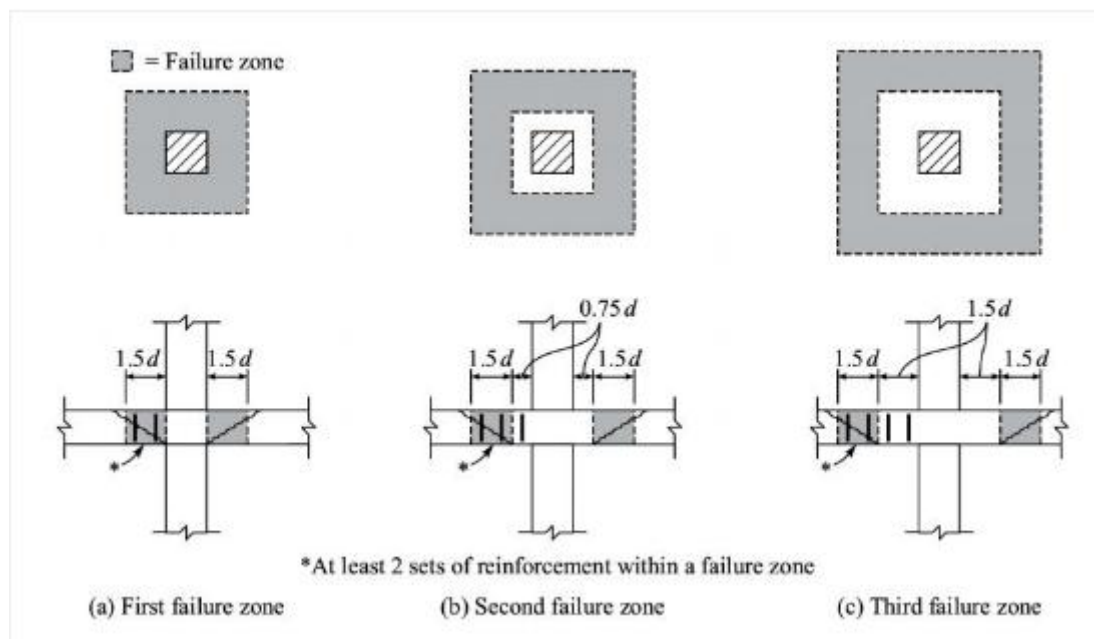


Figure (1.3): Various punching failure zones

1.2 Objectives

In this thesis at first , it is released a comparison between different codes like Egyptian code, ACI American code, euro code due to calculate punching shear loads failure. second , Another comparison between theoretical and experimental results. It is contained three variables in 7 samples